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ACQUISITION OF CLIMATIC DATA DURING TRANSPORTATION AND STORAGE OF CONTAINERS

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Army Natick Laboratories
Natick, Massachusetts

April 1975

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Humidity	Containers	Portable Equipment	
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of the studies summarized in this paper was to collect data on the conditions of temperature and humidity inside of various containers during shipment and/or storage. The information collected was used as an indication of the effectiveness of the packaging against the environment and as a guide to improved packaging methods.

The data, which is presented in the body of the report, was collected with a small, portable, battery operated temperature/humidity recorder placed inside the various containers under study.

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20. Abstract (cont'd)

One objective of the report is to illustrate the variety of studies which this instrumentation can support.

FOREWORD

This work was accomplished under the US Army Natick Development Center Project entitled "Packaging Technology – Establishment of Design Criteria for Containers – Acquisition of Shock, Load and Climatic Data During Transportation and Storage of Containers". This is Project Number 1T762713D552, Task Number 05, Work Unit Number 012.

The effort is a continuing investigation directed toward obtaining a statistical representation of the actual transportation environment to be used as a factual basis for scientific container design and laboratory transportation environment simulation tests. This report is a summary of those experimental studies which were conducted in the area of acquisition of climatic data during transportation and storage during the final development and testing of the instrumentation. One objective of the report is to illustrate the variety of ways in which the instrumentation can be used in support of packaging development studies.

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INTRODUCTION

One of the major obstacles in the development of effective packaging and container systems is the lack of reliable information relating to conditions encountered by supplies during shipment, handling, and storage. Container design in the past has been based chiefly on visual observations made over a long period of time of the actual performance of various package designs. In most instances the packages have excellent protective qualities but are overdesigned resulting in excessive material and labor costs. In some instances they are underdesigned resulting in damaged contents.

In order to obtain reliable information on conditions normally encountered by supplies during transportation and storage, the US Army Natick Development Center developed, through in-house and contractual efforts, three environmental recording systems for instrumenting shipping containers. Each system consists basically of a small lightweight, four-channel, battery operated tape recorder and the appropriate environmental sensors. The units are placed in containers which are incorporated into regular shipments and monitor conditions for a maximum period of six months. Upon completion of the shipment the magnetic tape is removed from the unit, and the recorded data is retrieved by processing the tape thru a precision tape deck and suitable display device or retrieval system as detailed in reference (1). A brief description of each system follows:

The acceleration recording system, described in reference (2), records the number of impacts, the impact magnitude, and the approximate impact time for the three principal axes of a container. It is impact actuated and has a range of five to one thousand g's. One unit has been prototyped.

The drop height system, described in reference (3), records the number of drops, the drop height, and the approximate drop time for the three principal axes of a container. It is impact actuated and has a range of 15 to 120 centimenters. Fifteen systems have been manufactured and are being used in studies of container size versus drop height and frequency of occurrence. The drop height data is being tabulated, and when a sufficient quantity is collected, it will be summarized and issued.

Development of the temperature/humidity recording system is described in detail in reference (4). Basically, however, the four channel battery powered recording unit, figures (1) and (2), consists of a base plate upon which is mounted coaxial supply and take-up reels, the recording head, stepping motor, batteries, timer, and potted electronic assemblies for controlling, stepping and recording. This assembly is inclosed in a protective aluminum box, figure (3). The timer is an Accutron device which has a contact closure once each hour. Contact closure triggers time pulse recording, tape advancement, and a forty-five second time delay. Tape advancement is accomplished by pulsing a rotary stepping motor to move the tape reels. At the conclusion of the time delay a univibrator is triggered causing recording on motionless magnetic tape. Two of the channels are reserved for hourly readings of the temperature and humidity inside the package, over the ranges of

-40°C to 65°C and 10% RH to 95% RH. Timing marks are recorded once each hour on the third channel to provide a time reference. A fourth channel is available for the hourly recording of other data such as the static compressive load on the package.

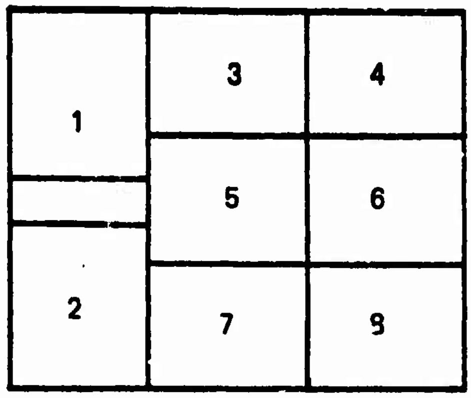
The temperature sensor, figure (4), is a network consisting of two parallel thermistor-resistor combinations in series, encapsulated in a protective Stycast resin. This sensor is used as one arm of a Wheatstone bridge across which is impressed at record time a regulated voltage pulse. The output of the bridge is fed to the recording head. The commerically available humidity sensor, figure (4), is a processed plastic wafer, which has an electrically conducting surface layer that is integral with the nonconducting substrate. The surface resistivity exhibits a logarithmic decrease with increasing relative humidity. The univibrator pulse is fed through the this sensor and a string of diodes in series with the sensor. The voltage across the diodes is picked off, amplified, and fed to the recording head. The diodes have the effect of straightening out the overall characteristic so that the recorded signal is near linear with relative humidity.

This report presents the results of actual field studies conducted using the temperature/humidity recording system in the areas of shipment, warehouse storage and outdoor storage during the time period of April 1971 to July 1973. These studies were made during the period of testing and improving the instrumentation, and the data are presented to provide a record of the instrumentation use and to indicate the range of studies which can utilize the instrumentation.

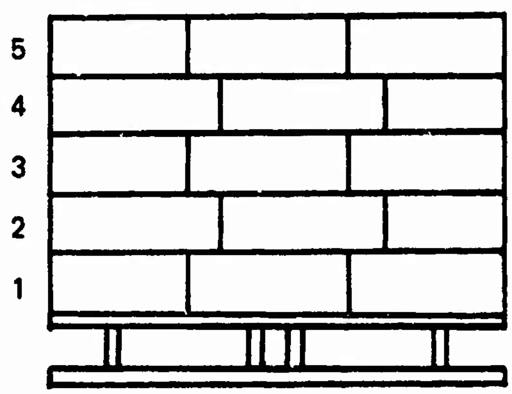
SHIPMENT

Initial field testing of the temperature/humidity recording system was accomplished by placing an active calibrated recorder, sensors, battery pack, and cushioning in a regular slotted fibreboard container approximately 41 cm x 31 cm x 24 cm and taping the container closed. This formed a test package with a total mass of approximately nine kilograms. The test packages were then routed via truck and airplane from Natick, Massachusetts to Wright Patterson Air Force Base, Ohio where they were subjected to a known environmental test series. Upon completion of the conditioning series the test packages were returned to Natick, Massachusetts via Air Mail, recalibrated, and the tapes were removed and analyzed. Figures (5) and (6) are graphical presentations of data gathered in this manner during two separate shipments in approximately the same time period.

An additional field test of six temperature/humidity recorders was conducted from August 1972 to January 1973 in conjunction with a packaging waste reduction study, reference (5). The recorders were calibrated at Natick, packaged individually in number 10 regular slotted fibreboard can cases (approximately 48 cm x 32 cm x 19 cm), taped, and air mailed to the Navy Supply Center, Charleston, S.C. At Charleston the recorders were positioned in three unit loads as shown below, and the loads were capped and strapped.



No. 10 Size Containers
8 Containers/Course
5 Courses/Pallet
40 Containers/Pallet



Location: Container No. 5 of Course No. 3 and Container No. 5 of Course No. 5.

The loads were then transported by Navy ship to Rota, Spain, placed in warehouse storage for twenty eight days, and returned by Navy ship to Charleston. See figures (7) through (10). From there the loads were transported by truck to Williamsburg, Virginia, subjected to additional handling, and then broken down. The recorders were returned by air mail to Natick where they were recalibrated before the tapes were removed and analyzed. Figures (11) and (12) are representative traces of the temperature and humidity conditions measured inside two individually instrumented packages during this field test.

Several recorder malfunctions and subsequent loss of data occurred because of the rough handling associated with these initial test shipments. These malfunctions highlighted some design deficiencies in the recorder systems which were corrected as they developed.

WAREHOUSE STORAGE

The purpose of this study was to determine if a significant temperature gradient existed between various levels of a four pallet tall configuration during normal warehouse storage. This information was to be correlated with the warehouse location versus shelf life of food products and the shelf life indications obtained with prototype "time/temperature" indicators, references (6) and (7), developed at Natick Development Center.

To this end a temperature/humidity recorder was modified to accept temperature signals on all four channels. The recorder was then sent to Tracy Army Depot, Tracy, California where a stack of four unit loads, instrumented with "time/temperature" indicators was also instrumented with recorder temperature sensors as shown below:

Temperature Sensor	Location
1	External top, 4.6m above floor
2	External middle, 2.4m above floor
3	Internal top, 4.6m above floor
4	External bottom, 1m above floor

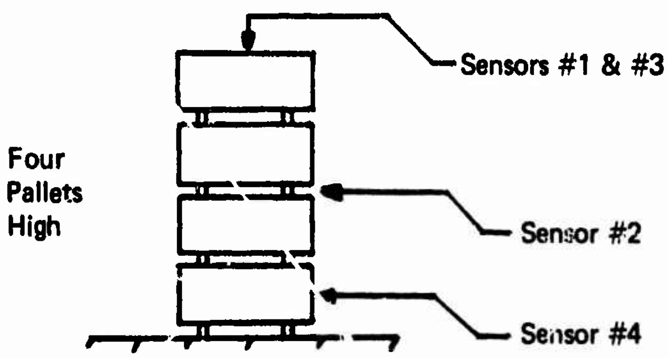


Figure (13) shows the temperature sensor being affixed to a case of subsistance items. Figure (14) is the four pallet instrumented load. The "time/temperature" indicators are visible on the bottom pallet load and on the one directly above it. Neither the temperature/humidity recorder nor the temperature sensors are visible in this figure. Figures (15) and (16), summarized in Tables (1) and (2) respectively, are representative data gathered during the study.

A statistical analysis, summarized in Table (3), of the complete data collected with the temperature/humidity recorder indicated that several significant temperature differences did exist at the 95% confidence level between various locations on the load. The results of the statistical analysis of the temperature/humidity recorder data agreed with the independent readings obtained from the prototype "time/temperature" indicators.

TABLE I

INTERNAL TOP TEMPERATURE VERSUS EXTERNAL TOP TEMPERATURE

Temperature (°C)	July 1972		August 1972	
	Sensor #3 Int Top	Sensor #1 Ext Top	Sensor #3 Int Top	Sensor #1 Ext Top
Mean High	31.1	33.5	30.8	31.8
Average	29.5	29.6	29.7	28.1
Mean Low	27.9	25.8	28.7	24.4
Cycle ±	1.6	3.8	1.0	3.7

TABLE 2

EXTERNAL TOP TEMPERATURE VERSUS EXTERNAL BOTTOM TEMPERATURE

Temperature (°C)	May 1973		June 1973	
	Sensor #4 Ext Bot	Sensor #1 Ext Top	Sensor #4 Ext Bot	Sensor #1 Ext Top
Mean High	28.9	35.8	31.4	38.7
Average	27.7	30.2	29.0	32.9
Mean Low	26.4	24.6	26.7	27.1
Cycle ±	1.3	5.6	2.3	5.8

TABLE 3

RESULTS OF STATISTICAL ANALYSIS

Sensor Locations	Significant Temperature Difference
Ext Top (1) vs Ext Mid (2)	Yes
Ext Top (1) vs Ext Bot (4)	Yes
Ext Top (1) vs Int Top (3)	No
Ext Mid (2) vs Ext Bot (4)	No
Ext Mid (2) vs Int Top (3)	Yes
Ext Bot (4) vs Int Top (3)	Yes

OUTDOOR STORAGE

The purpose of this study, described in detail in reference (8), was to determine the major causes of condensation within shrink film unit loads under outdoor storage conditions and develop methods which might reduce the damage caused by condensation after prolonged storage. The temperature/humidity recorder was used to measure the conditions inside of the unit loads in order to enable the development of a laboratory simulation test and to compare the effectiveness of several prototype unitizers designed to alleviate the problem.

The standard test procedure was to place a temperature/humidity recording system in a regular slotted fibreboard number 10 can case along with four number 10 cans. The case was then placed in the top center position of a 1 metre x 1.2 metre five course pallet load of number 10 can cases. The pallet load was then unitized with polymeric shrink film as shown in figure (17) and stored outside, subject to the weather, for various periods of time. After completion of the storage cycle the recorders were removed, and the data on the magnetic tape was retrieved and analyzed.

Figures (18) thru (20) represent the conditions in standard control loads. The relative humidity in the loads cycled from a low of approximately 40% to a high of approximately 95% on a daily basis. When this data was correlated with observations of the prevailing

weather conditions (rain, sun, cloudy) during the storage period it indicated that direct exposure to sunlight and not prevailing outside humidity was the major driving factor causing moisture to collect on the top inside of a fully enclosed shrink film unit load. Figure (19) is an excellent illustration of this point. The sixth, seventh, and tenth of October were cloudy, rainy days, and yet, the relative humidity at the top of the load never exceeded 75%. Conversely, the eighth, ninth, eleventh, and twelveth of October were bright sunny days, but the peak relative humidity in the load exceeded 90%.

The rapid rise in average relative humidity level evident in figures (20) and (21) was caused by tears in the polyethylene shrink wrap which occurrad during the outdoor storage period.

Efforts were made to decrease the amount of moisture available inside the load prior to shrink wrapping and outdoor storage. To this end; one load was preconditionad at 60°C, 10% RH prior to shrink wrapping, and another load was constructed of low moisture content wax impregnated number 10 fibreboard can cases. Figures (21) and (22) represent the conditions inside these loads when subjected to outdoor storage. The peak relative humidity in these loads prior to the tear in the protective film of the 60°C, 10% RH pallet, never exceeded 70%. This indicated that a prime source of the moisture causing high relative humidities was the fibreboard can cases.

Figure (23) represents the conditions in an experimental load in which the top course of containers was isolated from the remaining load by a heat sealed sheet of polyethylene. Moisture driven out of the bottom four courses could not collect in the top course of this unit load. Peak recorded relative humidity in the top layer never exceeded 55%. This confirmed the previous indication that the fibreboard was the prime source of moisture.

CONCLUDING REMARKS

The data presented in this report represent the conditions of temperature and humidity recorded inside packages during actual shipment and storage. It can be used as a guide to environmental conditions present in several specific applications and as an indication of possible uses of the temperature/humidity recorder in environmental data acquisition for scientific container design and prototype package evaluations.

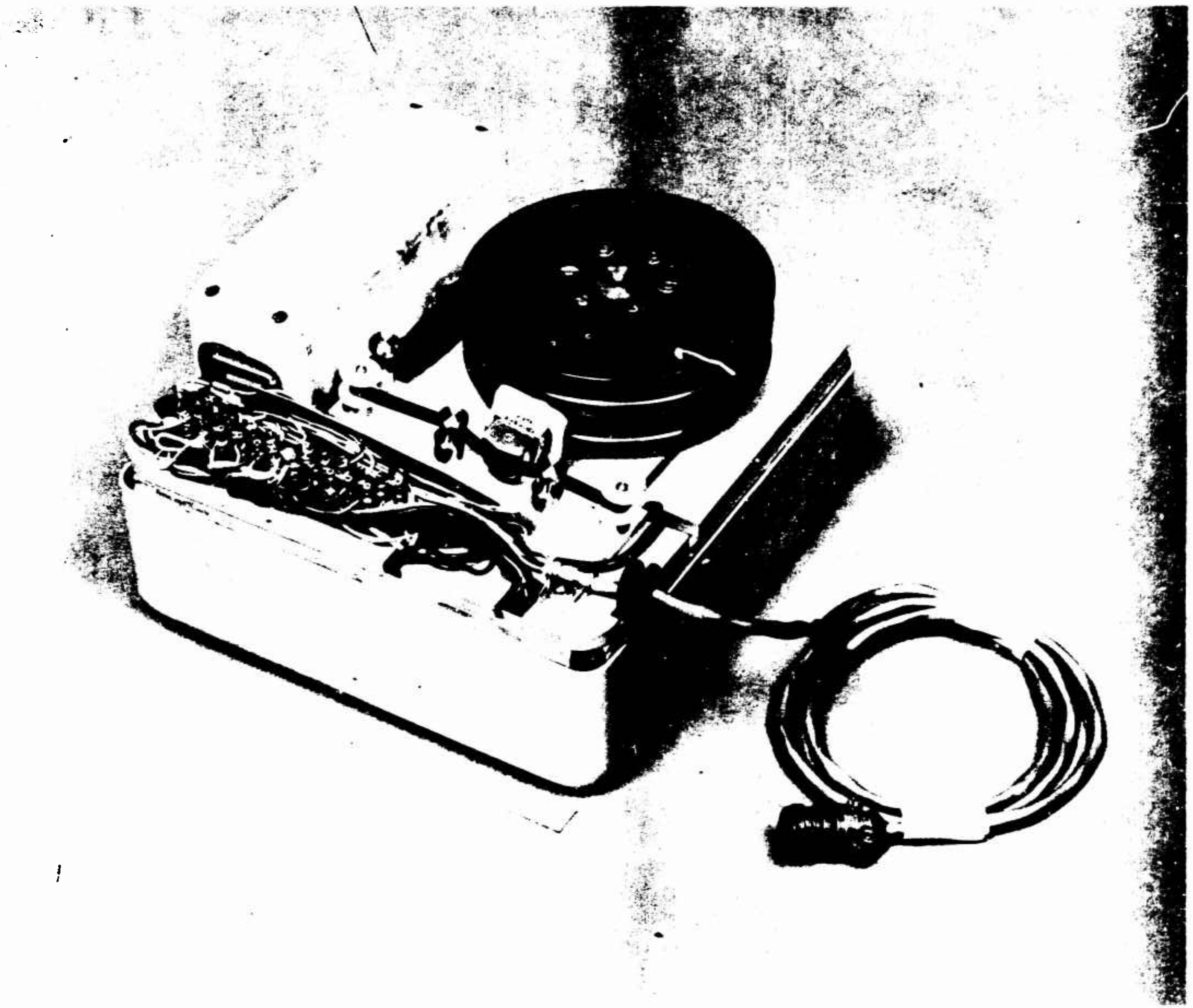


Figure 1. Temperature/Humidity Recorder, Top View. Coaxial supply and take-up reels, recording head, terminal board, electronics can, and input connector visible.

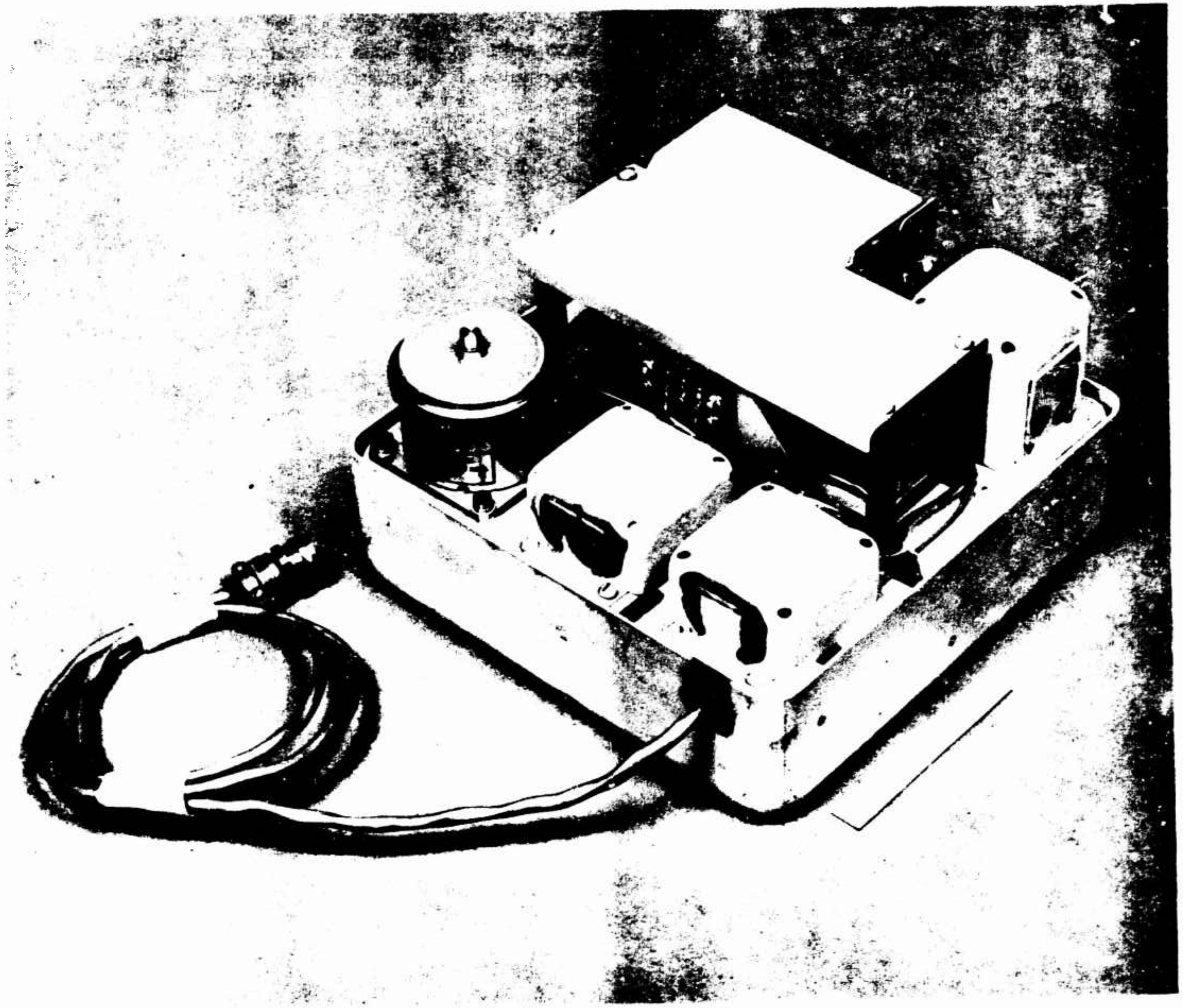


Figure 2. Temperature/Humidity Recorder, Bottom View. Potted electronic cans, capacitor mounting bracket, 45 volt battery hold down, power supply terminal board, and rotary stepping motor visible.

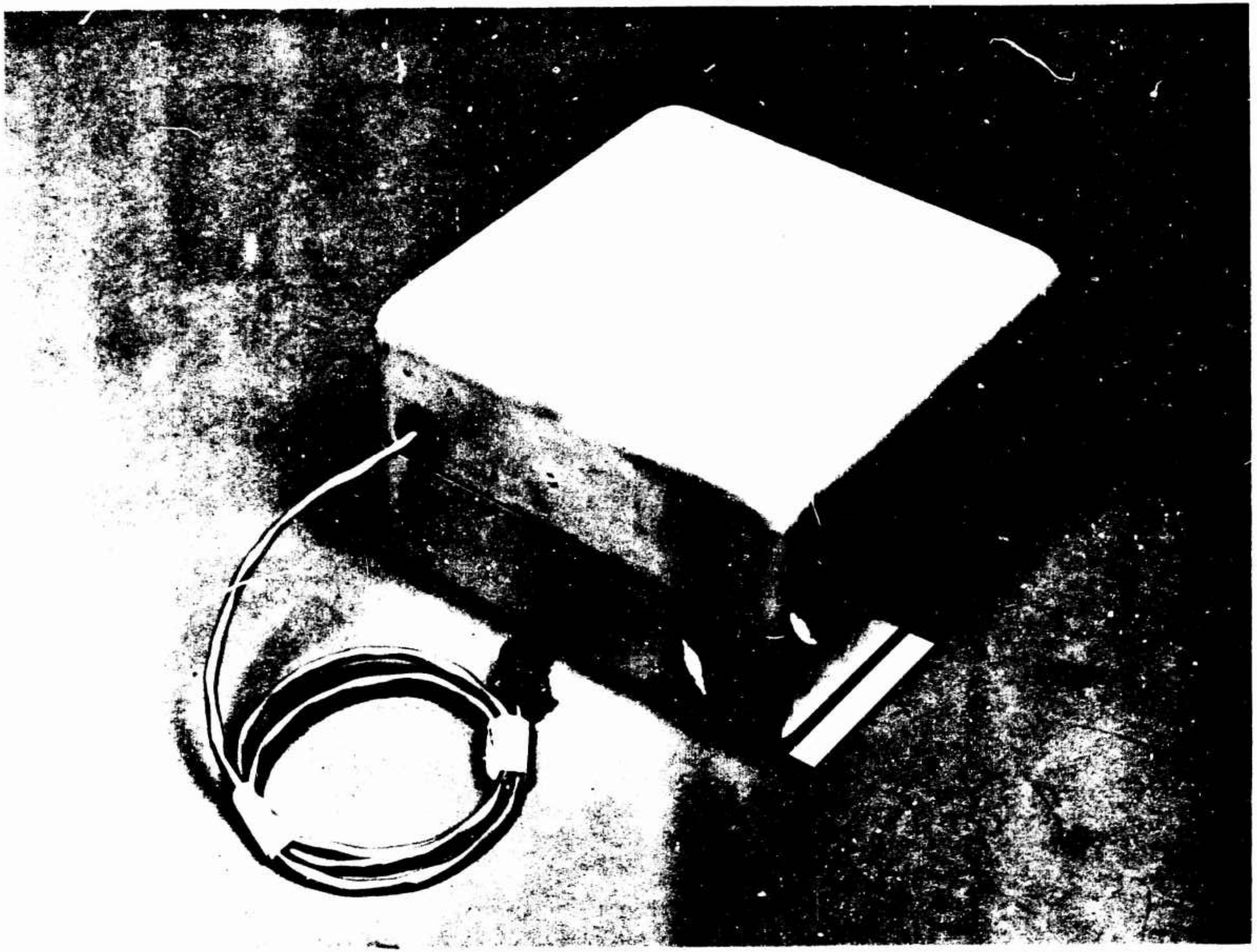


Figure 3. Temperat re/Humidity Recorder, Protective Cover. Eighteen centimeters long by eighteen centimet s wide by thirteen centimeters deep.

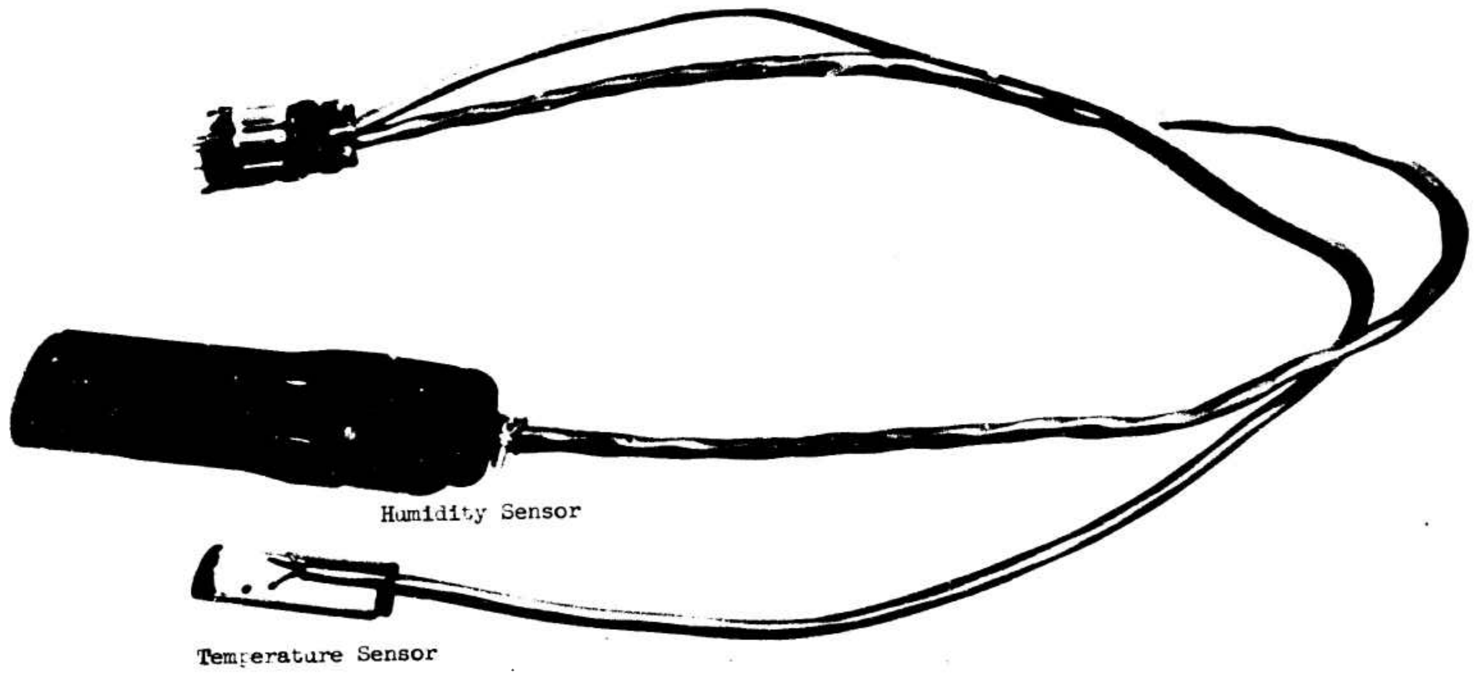


Figure 4. Temperature and Humidity Sensors. From front to back: temperature sensor, one centimeter in diameter by four centimeters long; humidity sensor, three centimeters in diameter by eleven centimeters long; and connector.

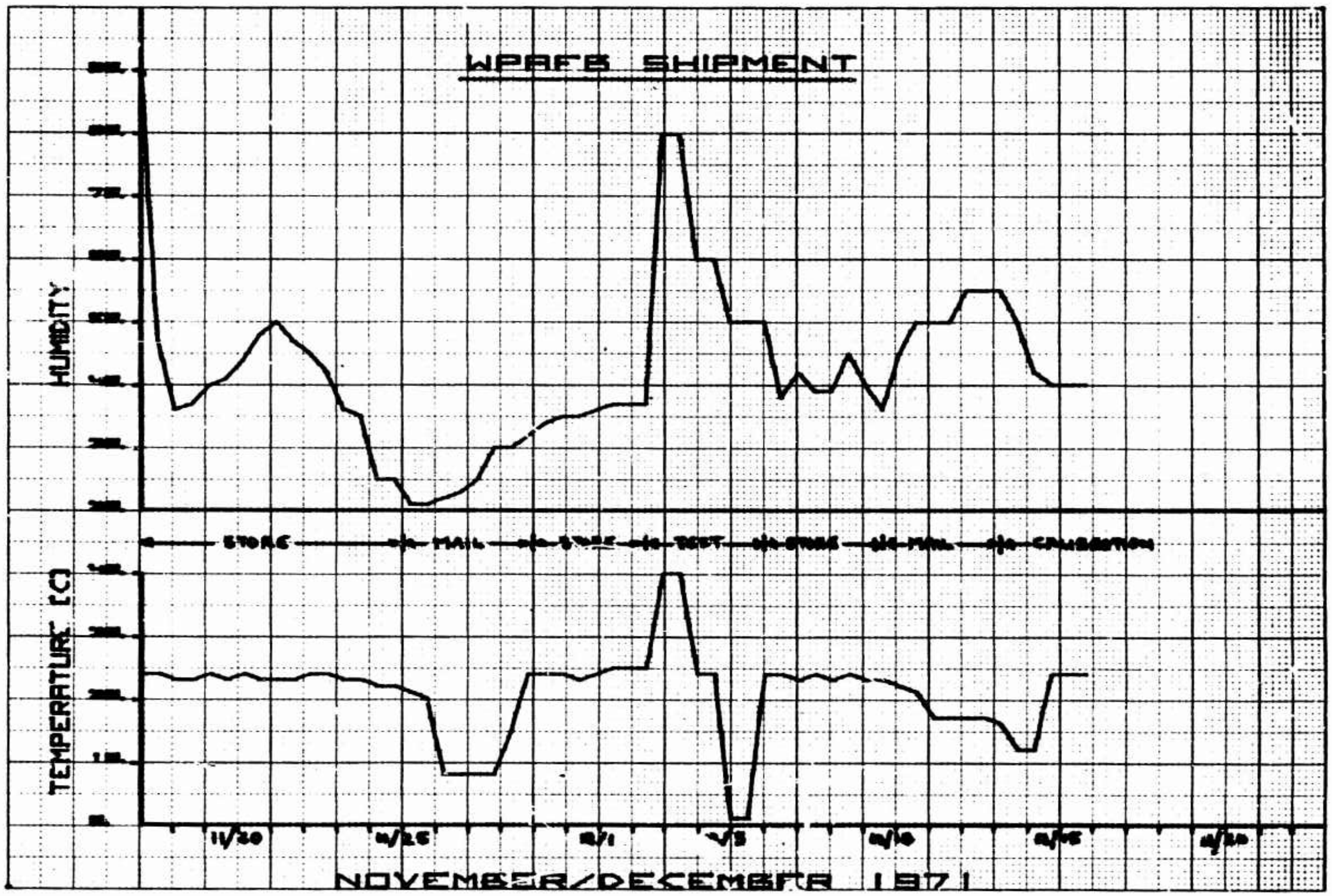


Figure 5. Wright Patterson Air Force Base Shipment, November/December 1971. 17 November to 25 November, storage; 25 November to 28 November, postal system; 28 November to 1 December, storage; 1 December to 6 December, test series; 6 December to 9 December, storage; 9 December to 13 December, postal service; and 13 December to 16 December, final calibration series.

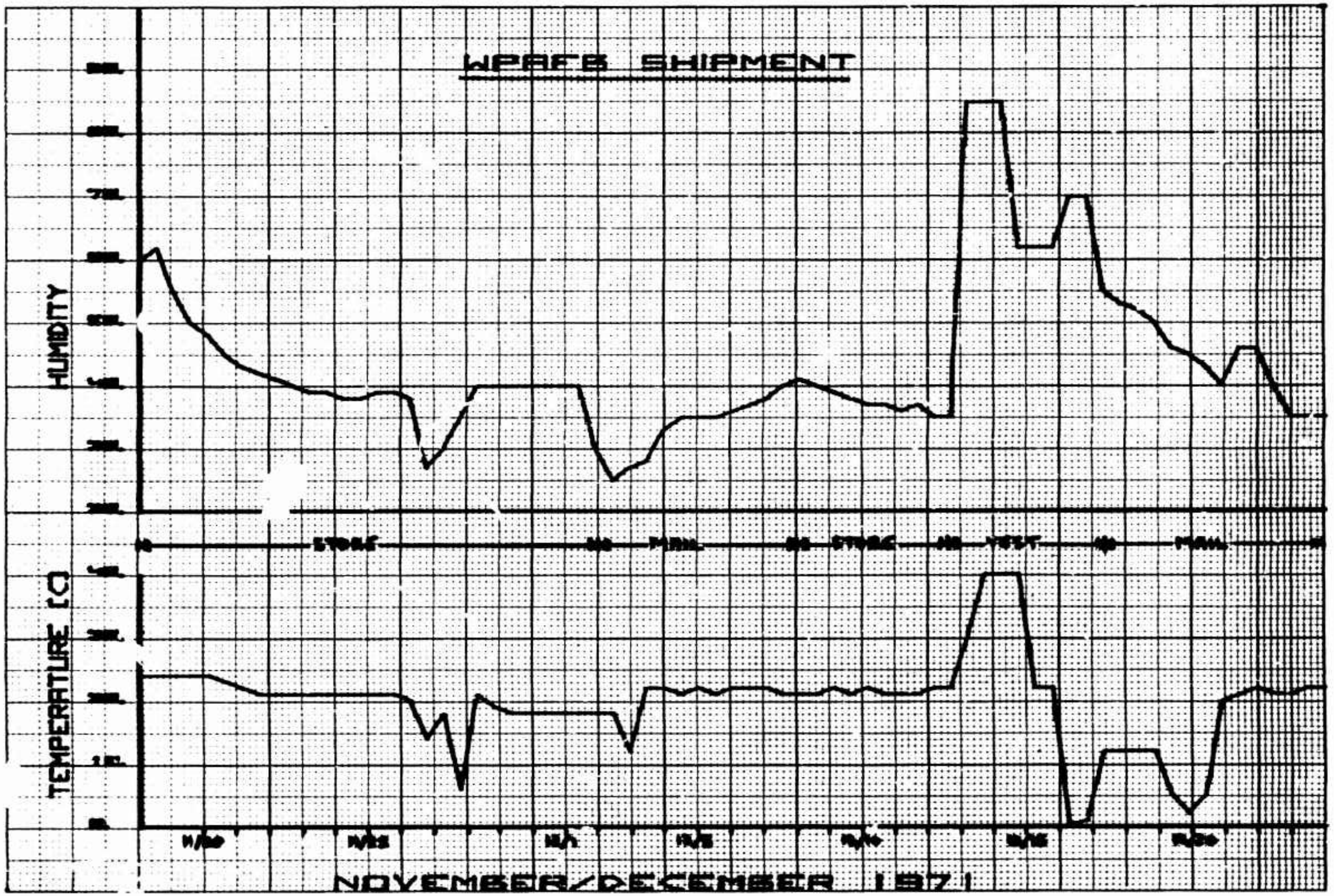


Figure 6. Wright Patterson Air Force Base Shipment, November/December 1971. 19 November to 2 December, storage; 2 December to 8 December, postal service, 8 December to 12 December, storage; 12 December to 17 December, test series; and 17 December to 24 December, postal service.

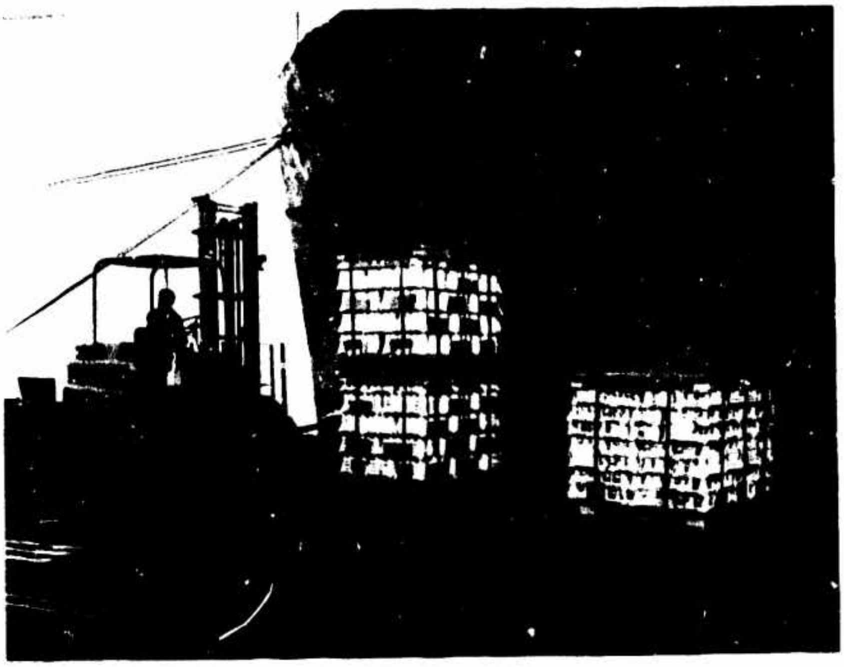


Figure 7. Rota Spain Shipment, Loading.

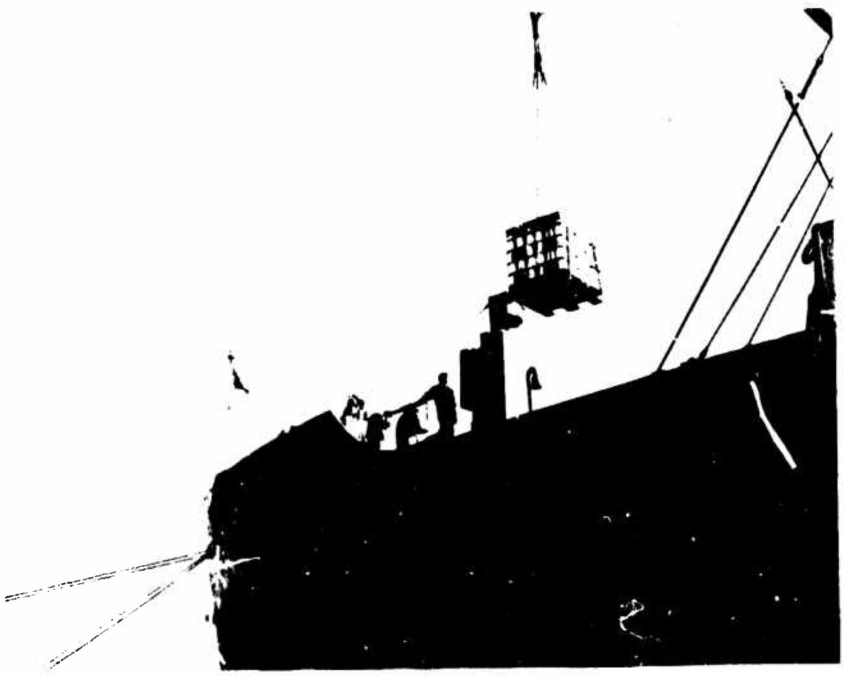


Figure 8. Rota Spain Shipment, Loading.

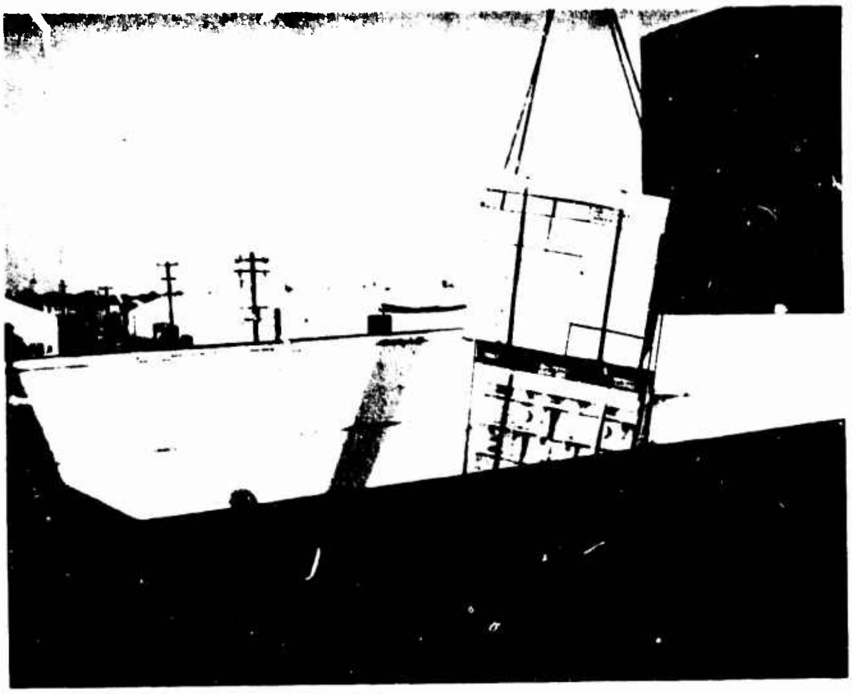


Figure 9. Rota Spain Shipment, Loading.

Figure 10. Rota Spain Shipment, Storage.

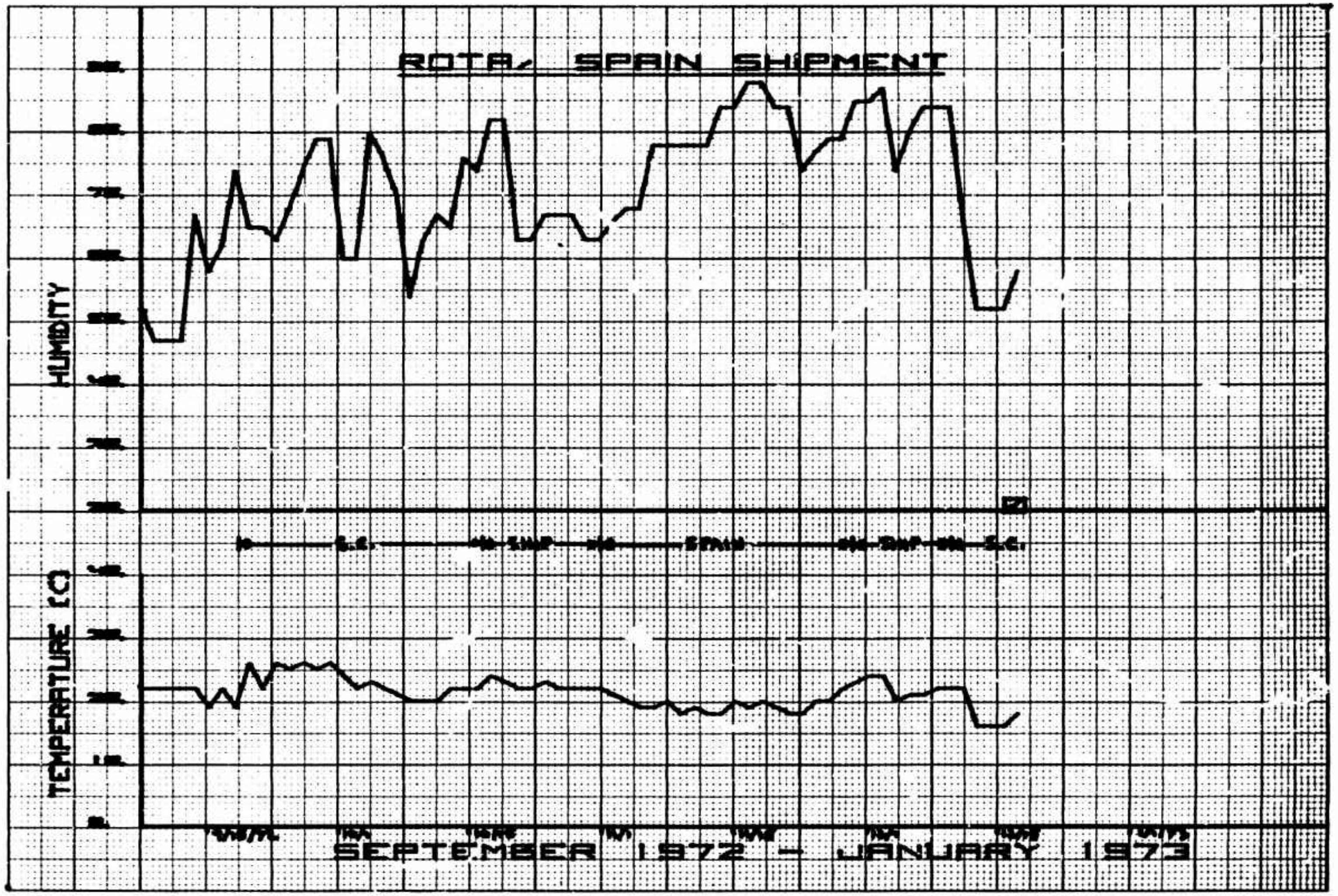


Figure 11. Rota, Spain Shipment, Climatic Conditions. 15 September to 17 October, assembly and storage in South Carolina; 17 October to 30 October, ocean shipment to Spain; 30 October to 28 November, warehouse storage in Spain; 28 November to 9 December, ocean shipment to South Carolina; and 9 December to 17 December, storage and disassembly in South Carolina.

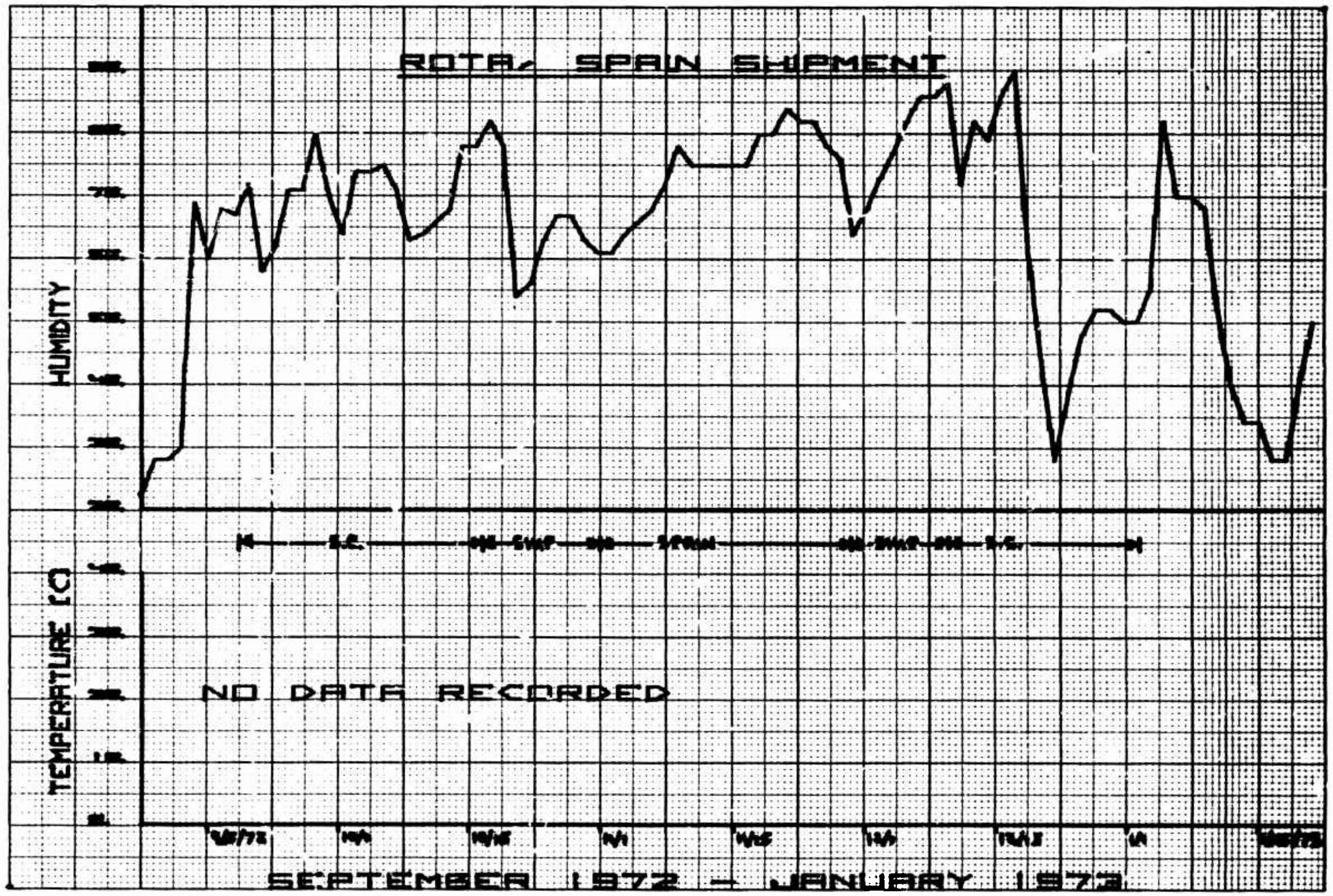


Figure 12. Rota, Spain Shipment, Climatic Conditions. 15 September to 17 October, assembly and storage in South Carolina; 17 October to 30 October, ocean shipment to Spain; 30 October to 28 November, warehouse storage in Spain; 28 November to 9 December, ocean shipment to South Carolina; and 9 December to 17 December, storage and disassembly in South Carolina. A malfunction occurred in the temperature channel circuitry and consequently no temperature data was recorded.

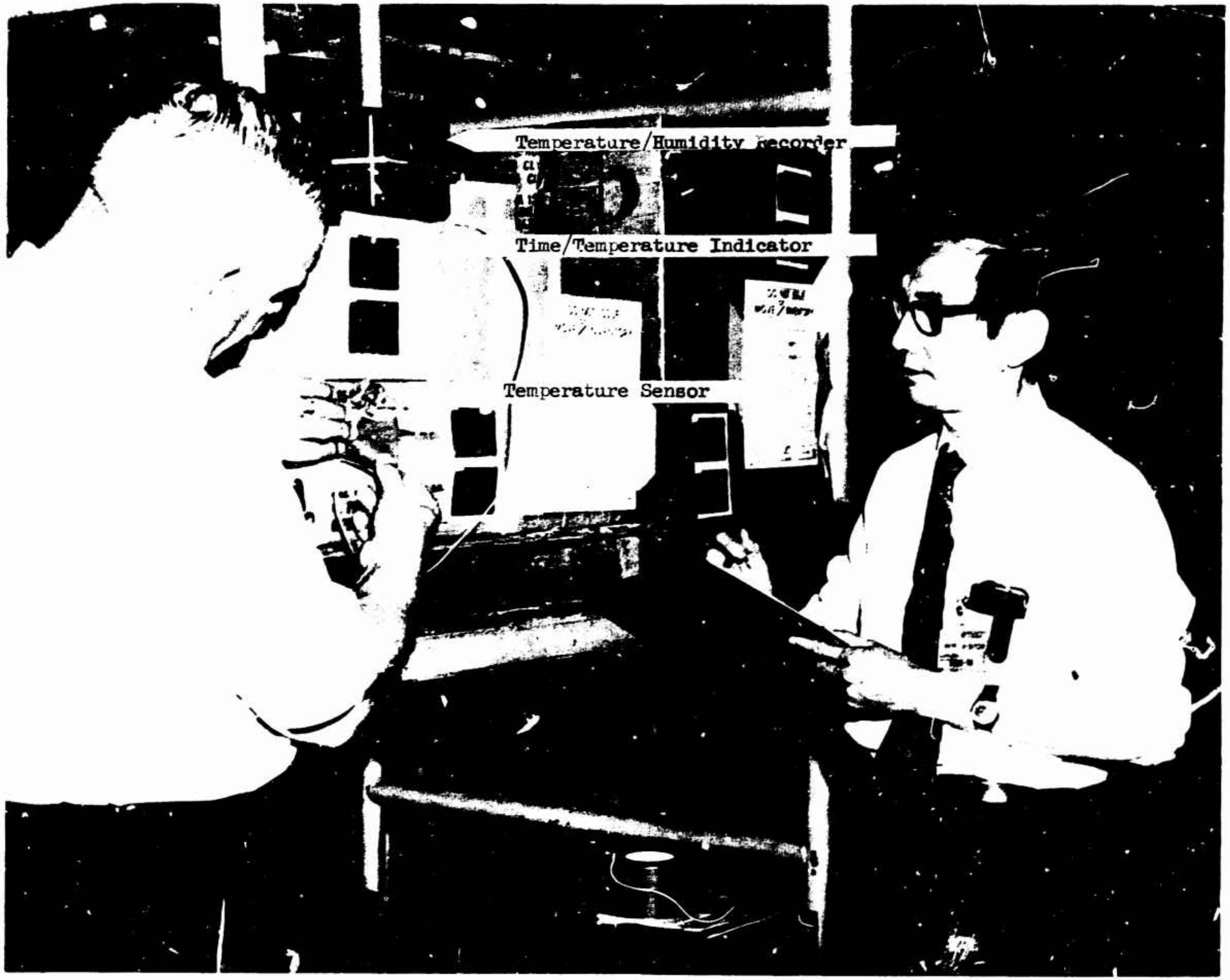


Figure 13. Depot Tracy Storage, Sensor Installation. The temperature/humidity recorder, "time/temperature" indicators, and a temperature sensor are visible.

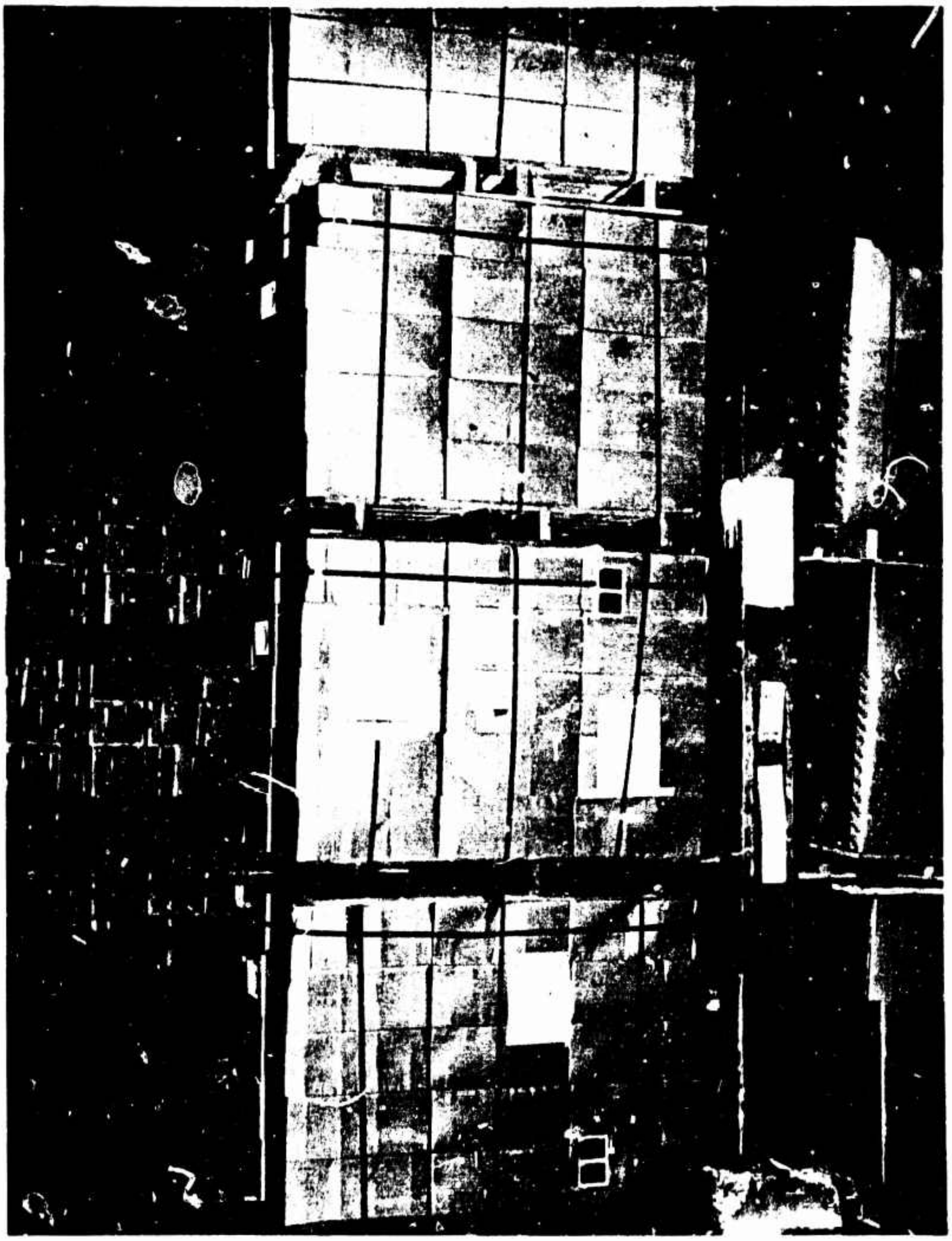


Figure 14. Depot Tracy Storage, Load Configuration. The "time/temperature" indicators are visible on the bottom pallet load and on the one directly above it. Neither the temperature/humidity recorder nor the temperature sensors are visible. Total stack height is approximately 4.6 metres.

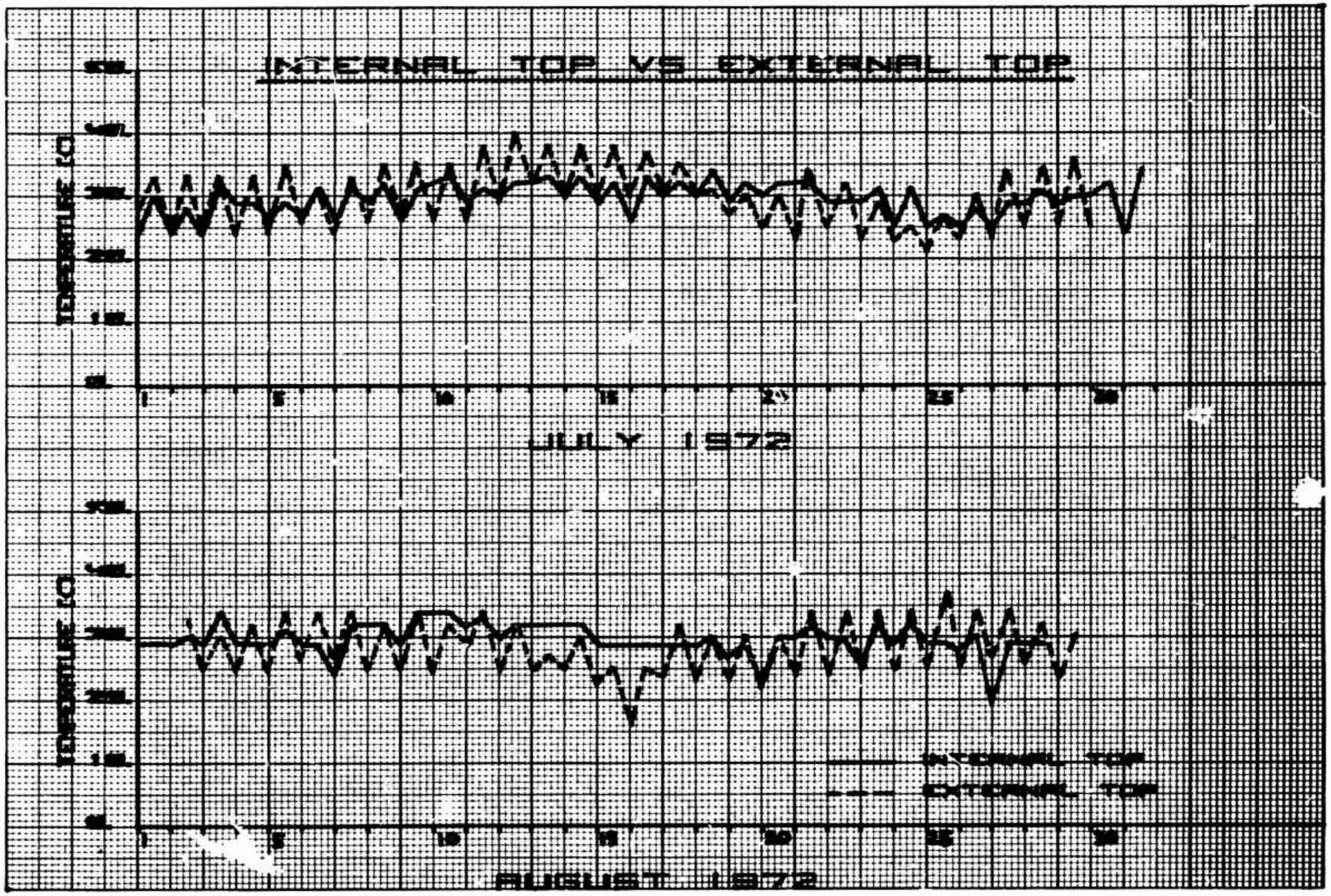


Figure 15. Depot Tracy Storage, July/August 1972. Internal top temperature compared against external top temperature. Although the external top temperature exhibited a greater cycle, no significant difference existed between the two average temperatures.

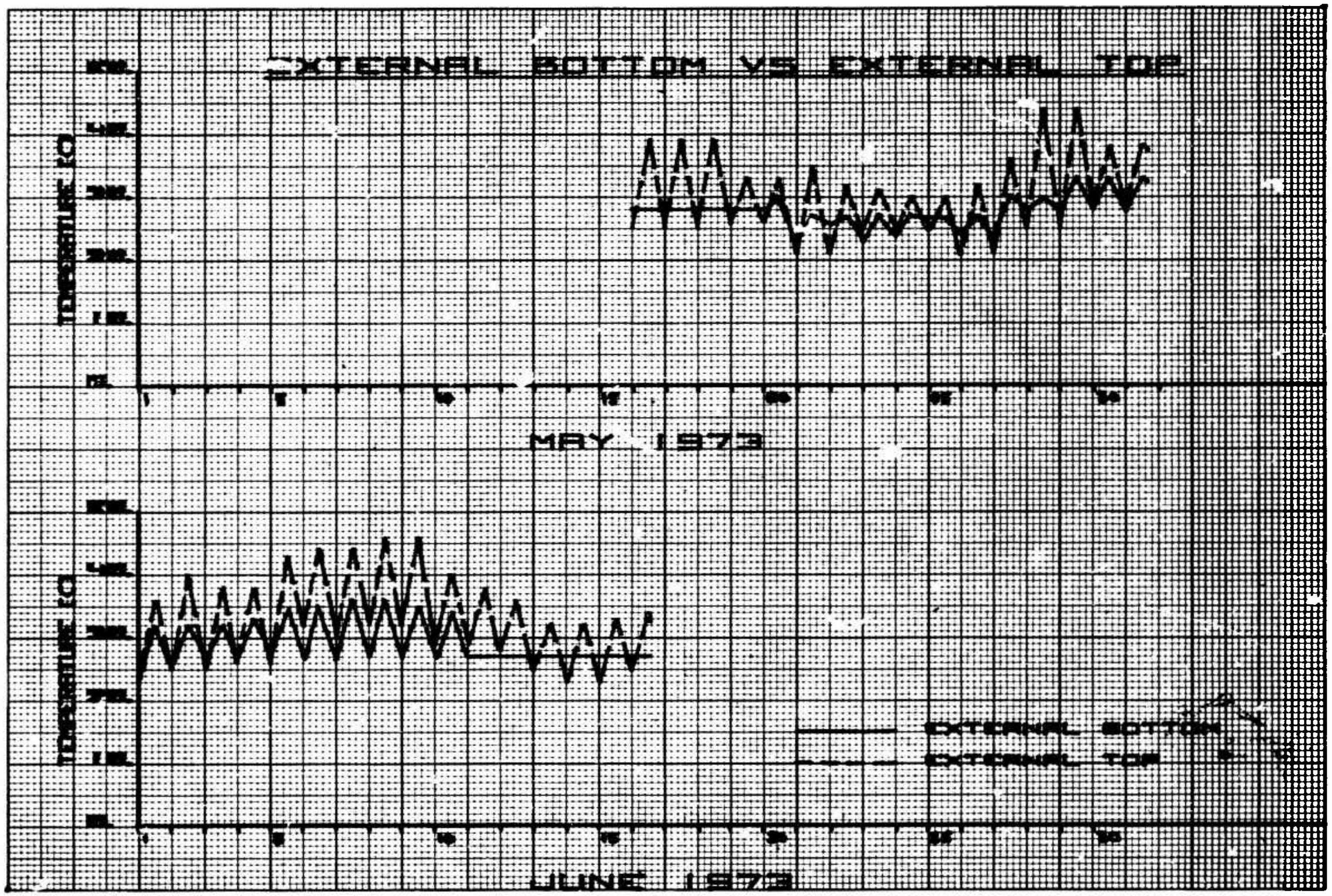


Figure 16. Depot Tracy Storage, May/June 1973. External bottom temperature compared against external top temperature. The average external bottom temperature is significantly lower than the average external top temperature.

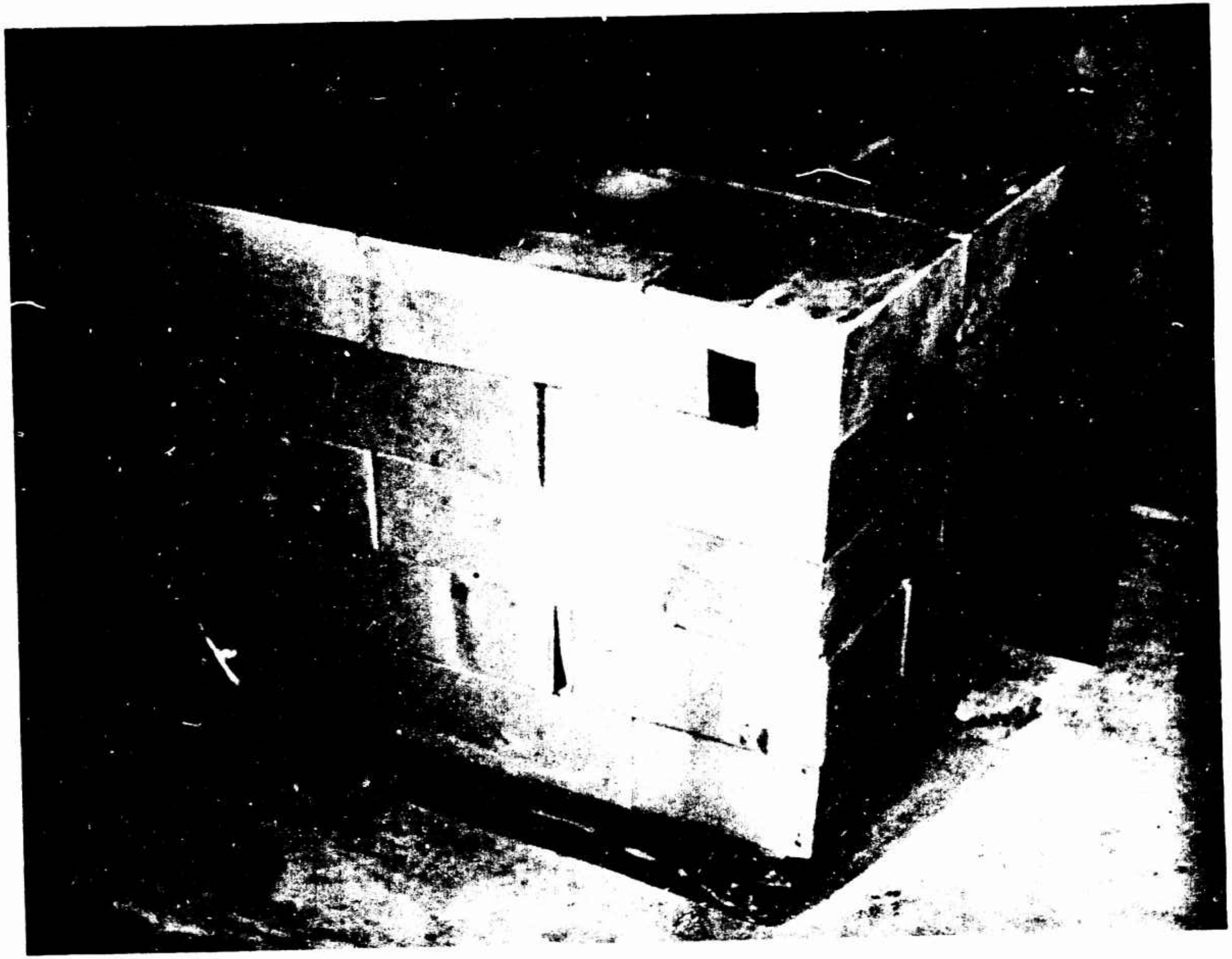


Figure 17. Shrink Wrapped Unit Load. Forty number 10 can cases unitized with polymeric shrink film forming a unit load approximately 1 metre by 1.2 metres by 1.1 metres high.

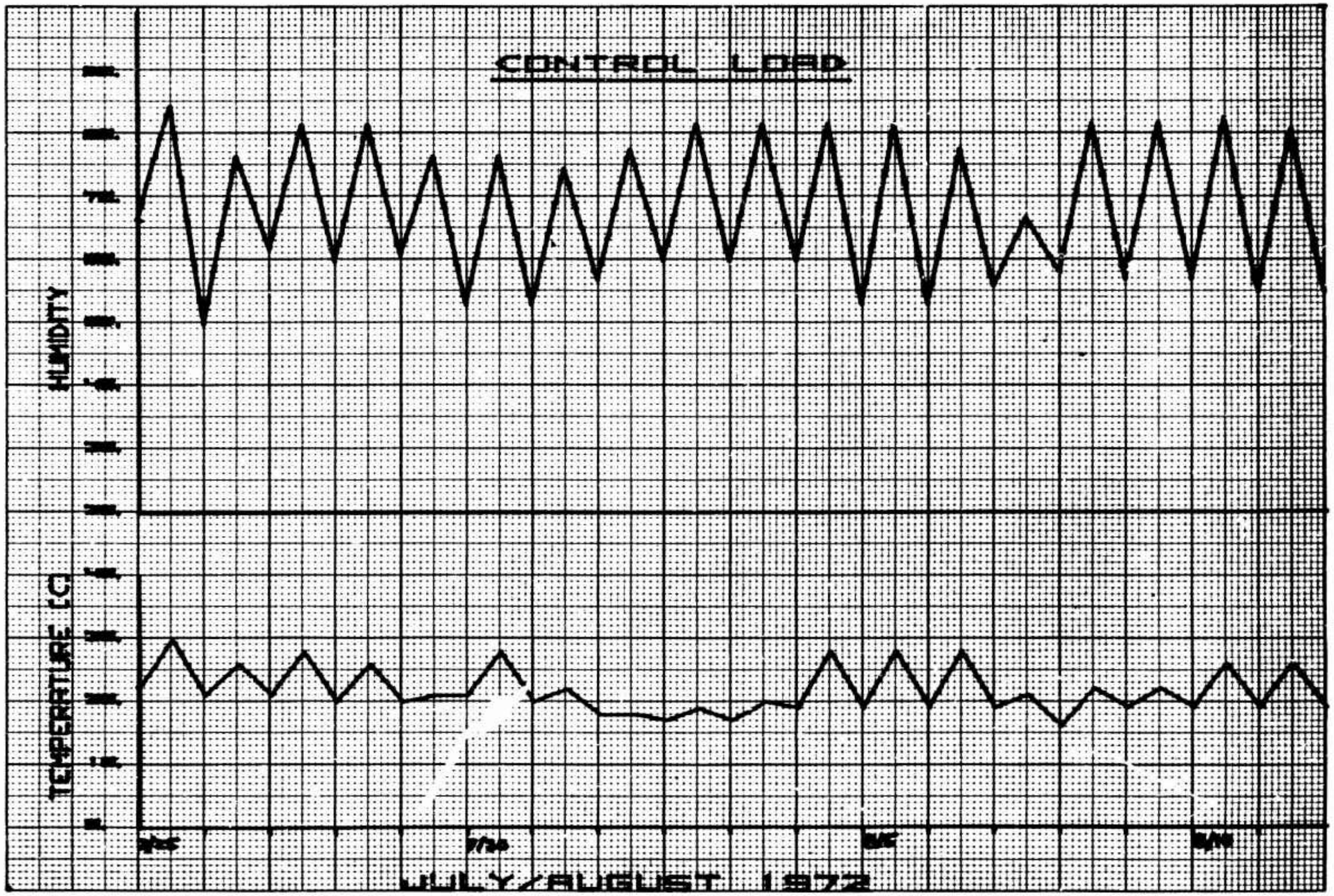


Figure 18. Outdoor Storage, July/August 1972. Normal twenty-four hour cycle of temperature and humidity conditions inside the top layer of a shrink film unit load subject to outdoor storage conditions.

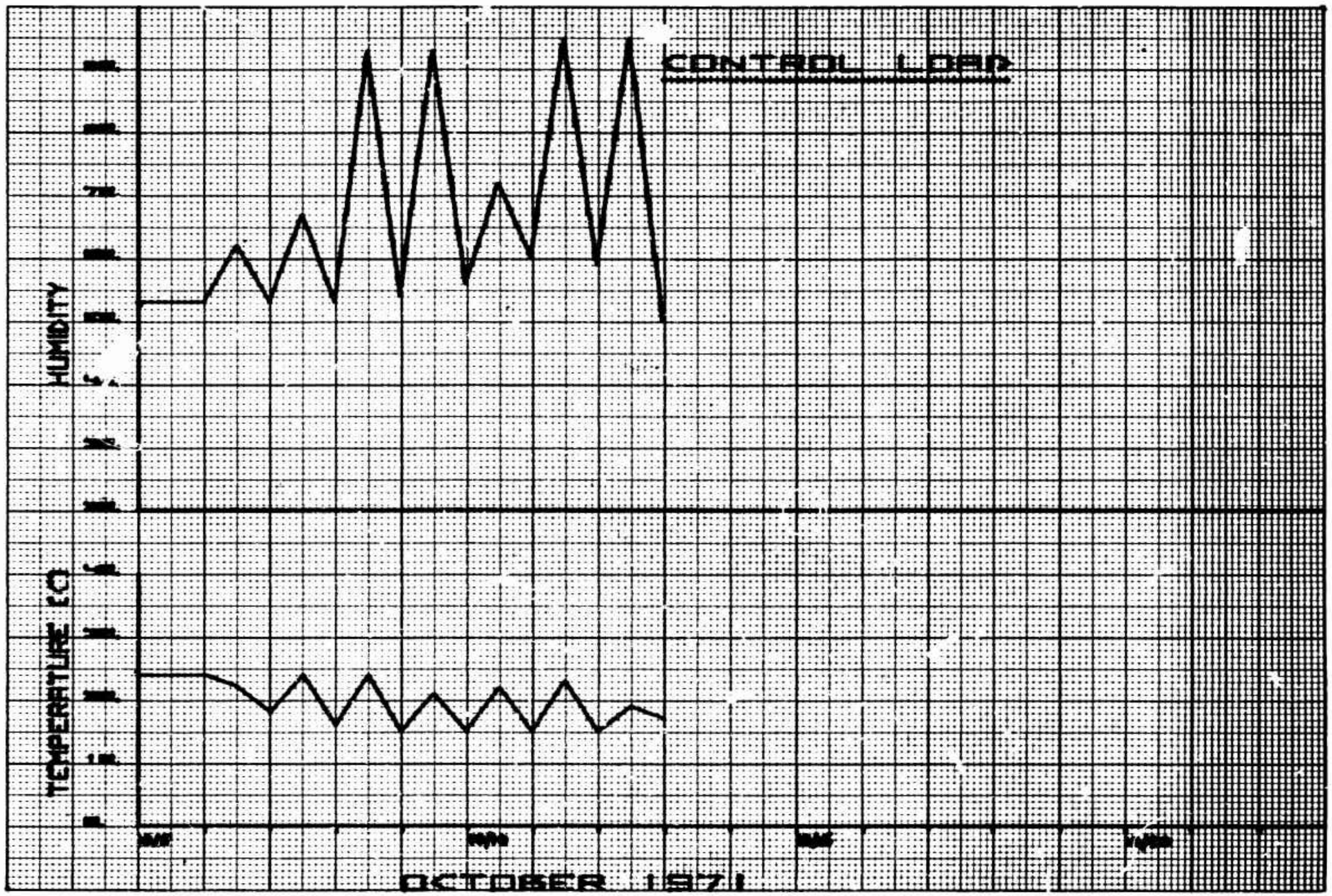


Figure 19. Outdoor Storage, October 1971. Normal twenty-four hour cycle of temperature and humidity conditions inside the top layer of a shrink film unit load subject to outdoor storage conditions. The sixth, seventh, and tenth were cloudy and rainy days. The eighth, ninth, eleventh, and twelveth were bright sunny days.

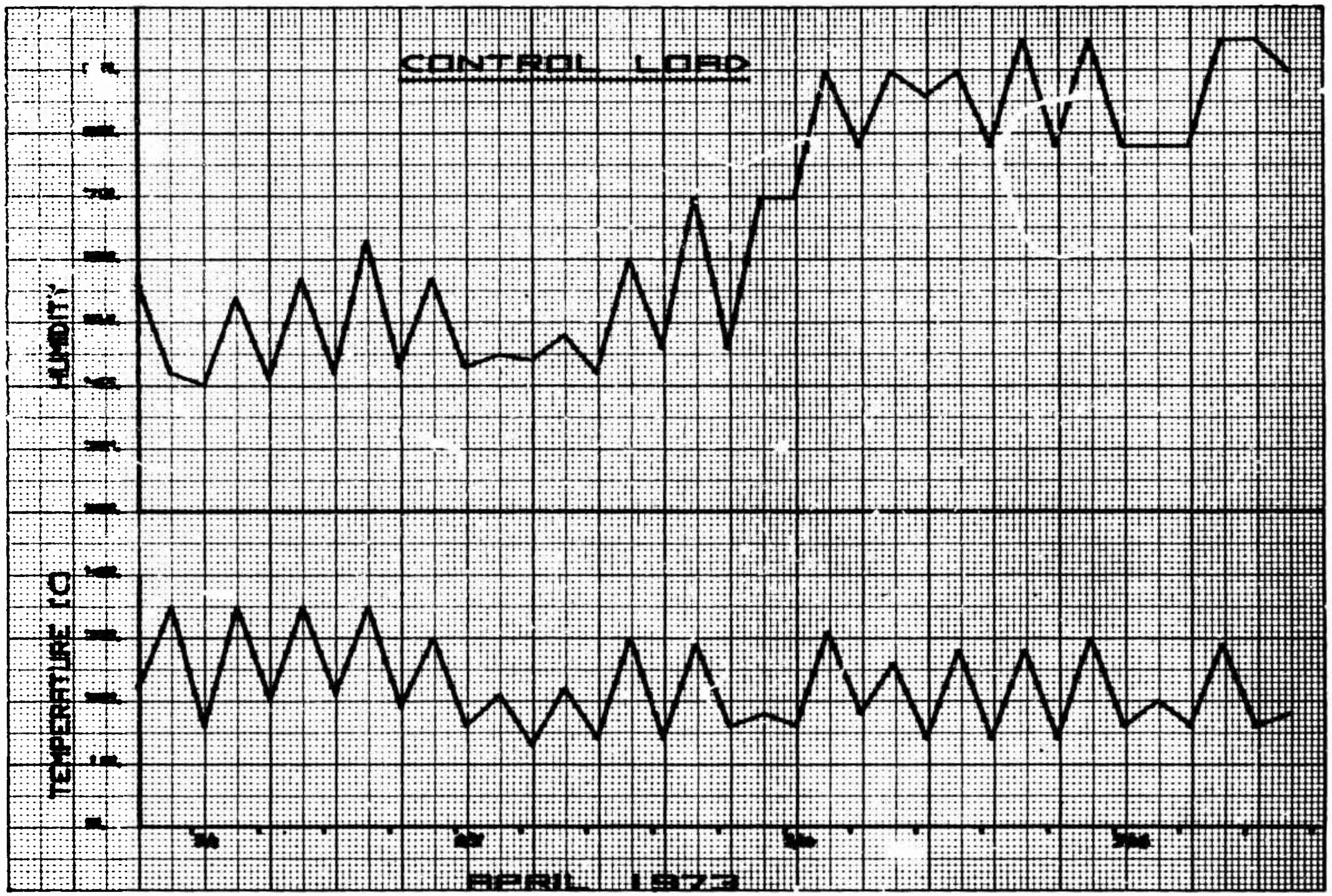


Figure 20. Outdoor Storage, April 1973. Normal twenty-four hour cycle of temperature and humidity conditions inside the top layer of a shrink film unit load subject to outdoor storage conditions. Dramatic increase in relative humidity occurring on 10 April was caused by a tear in the shrink film.

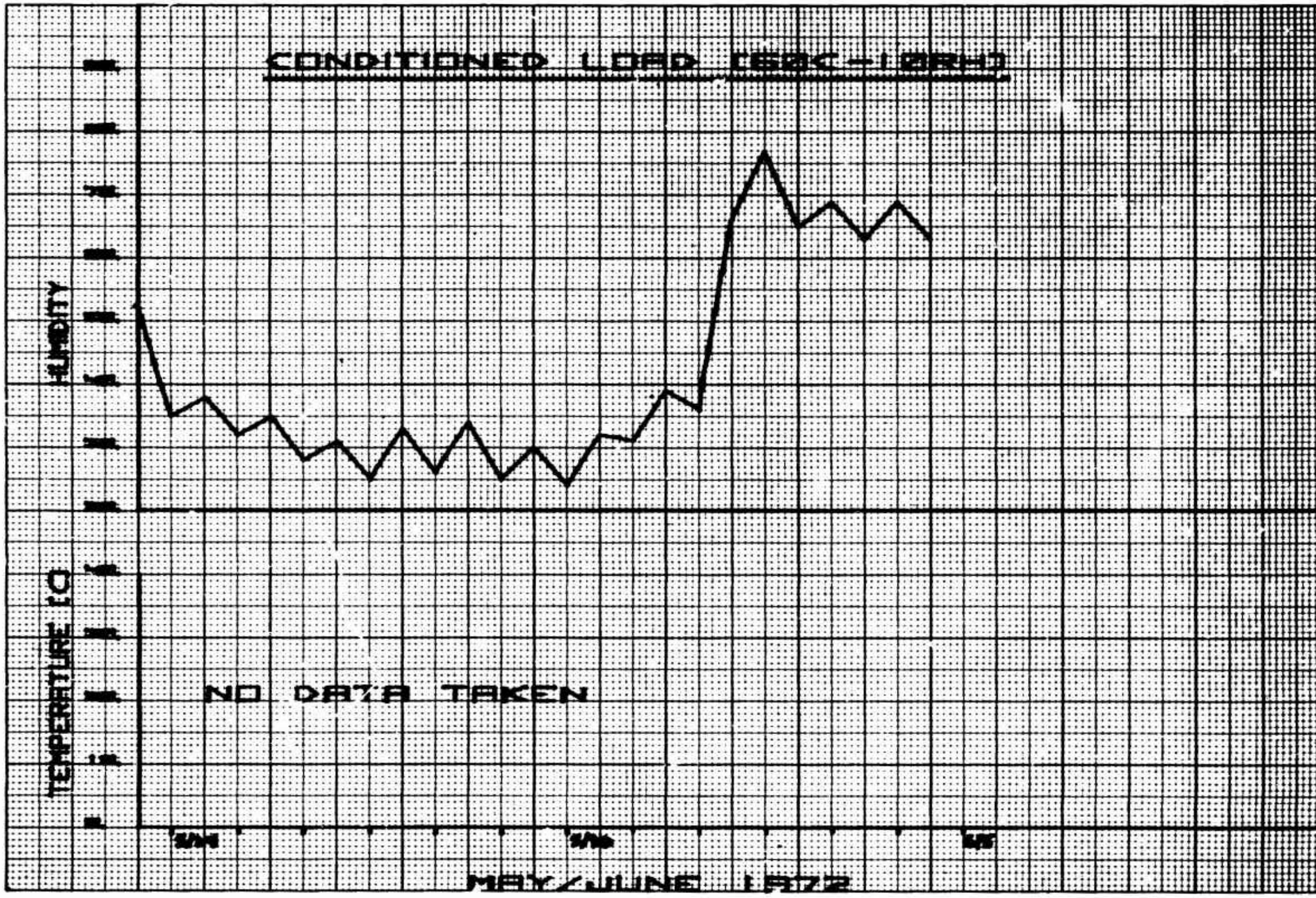


Figure 21. Outdoor Storage, May/June 1972. Temperature and relative humidity inside unit load preconditioned at 60°C and 10% RH and then subjected to outdoor storage. Dramatic increase in relative humidity occurring on 1 May was caused by a tear in the shrink film. No temperature data was recorded due to a malfunction in the temperature circuitry.

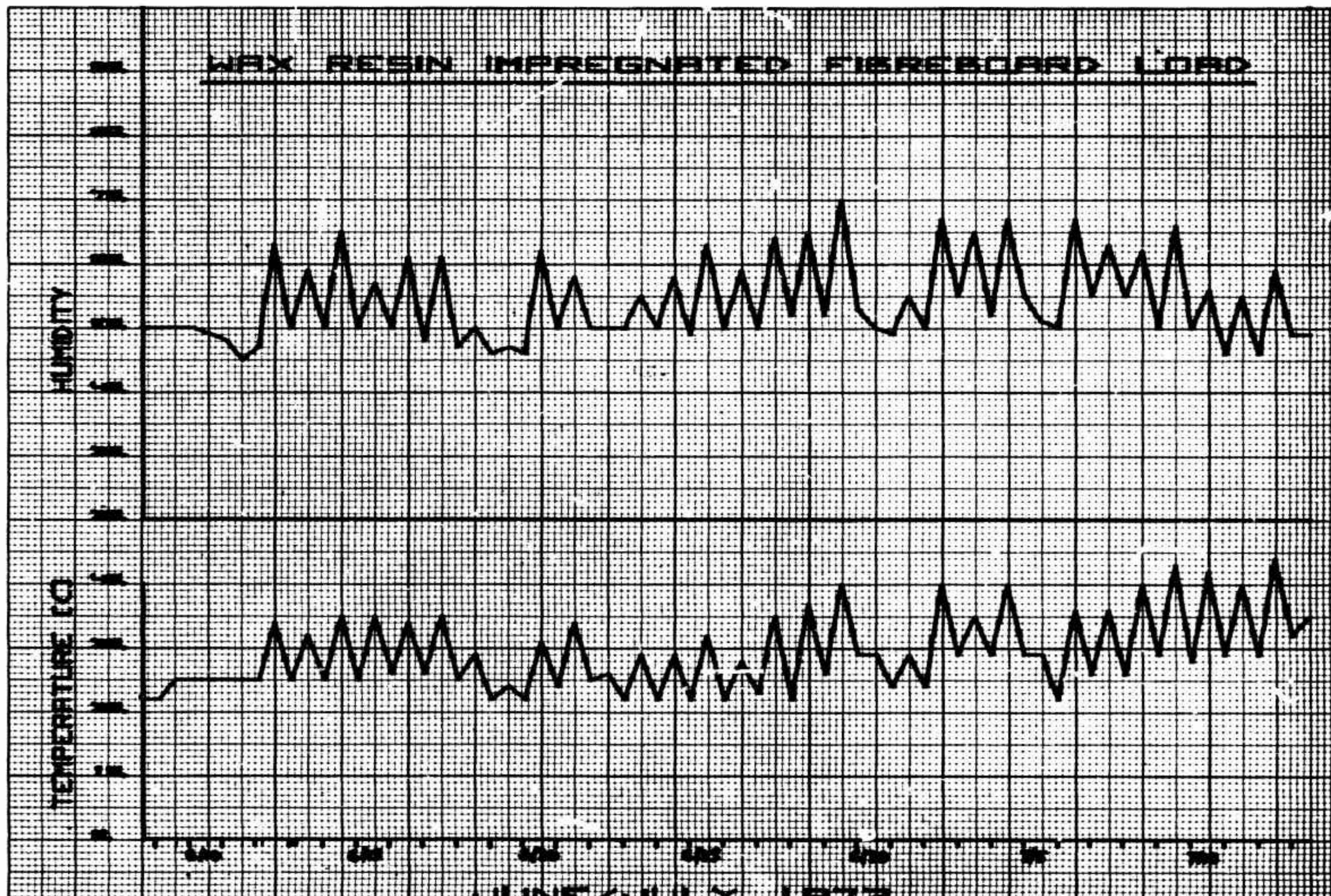


Figure 22. Outdoor Storage, June/July 1972. Temperature and relative humidity inside of unit load of number 10 can cases constructed from wax resin impregnated fibreboard.

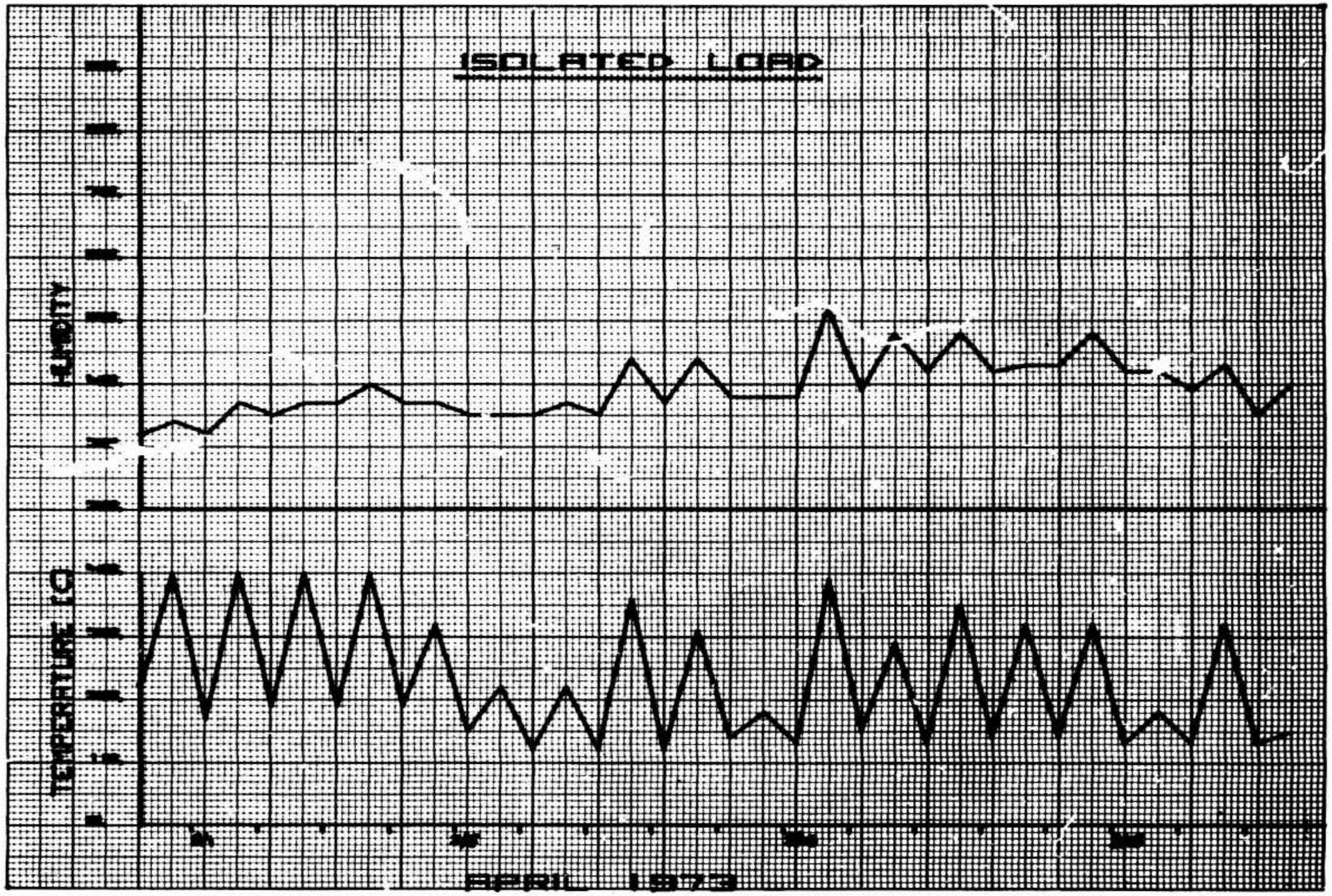


Figure 23. Outdoor Storage, April 1973. Temperature and relative humidity inside the top layer of a unit load in which top layer of number 10 can cases is isolated from the remaining load by a heat sealed sheet of polyethylene.

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